CROSS-MODAL TRANSFER IN A PAIRED-ASSOCIATE TASK IN PATIENTS WITH UNILATERAL CEREBRAL LESIONS

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CROSS-MODAL TRANSFER IN A PAIRED-ASSOCIATE TASK

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SUMMARY

Twenty-seven subjects were divided into three groups, one group having left hemisphere brain lesions, one group having right hemisphere lesions and a control group having no known brain lesions. Each subject was tested on his performance in learning an association between a nonsense form and a letter of the alphabet. The same association was learned in each of two modalities, touch and vision, with subjects learning the association in one modality for the original learning task and relearning it in the other modality for the transfer task. Test results were measured in two ways: (1) the number of trials required to reach a criterion of two consecutive correct trials and (2) the number of errors made in each task before criterion was reached.

Of the nine subjects in the left brain-damaged group, only two were able to reach criterion in the learning task; as a result their test results were not included in the analysis. The right brain-damaged group was significantly inferior to the control group in learning the original material, but there was not a significant difference in cross-modal transfer between these two groups. Visual learning did not differ significantly from tactual learning in the original task, and in the transfer, visual to tactual did not differ significantly from tactual to visual.

CHAPTER I

INTRODUCTION

Methods for Studying Operations of the Separate Cerebral Hemispheres

Special techniques have made it possible to study the operations of the separate hemispheres of the brain. One common method in visual studies involves the use of a special projector called a tachistoscope which flashes a visual image at any given point for a time as brief as one millisecond. Thus the image can be limited to one visual half field. Hines (1972) and Hines and Satz (1971) investigated the use of this technique under various conditions such as single or simultaneous presentation to each visual field, with or without a central fixation point and at graded rates of presentation.

Methods used to investigate hemispheric functions in tactual studies include a variety of ways of measuring manual sensory skills. The most widely used one is the haptic recognition of stimuli with the dominant or non-dominant hand, or in the case of the brain damaged, by the hand ipsilateral or contralateral to the lesion. Hermelin and O'Connor (1971) tested the ability of blind subjects to read Braille with their right and left hands and compared the performance of the two. Similarly, Milner and Taylor (1972) tested each hand of subjects with midline interhemispheric sections on the ability to match tactual patterns. Other methods include tactual maze searching (DeRenzi, Faglioni and Scotti, 1970), discrimination of roughness, texture, size, form and pattern (Semmes, 1965), discrimination of direction of tactile stimuli to the palm (Fontenot and Benton, 1971) and measurement of sensory capacities for discrimination of passive movement, touch-pressure thresholds, two-point discrimination and point localization (Semmes, 1968).

Control of the stimulus itself comprises a third and major method of comparing the two hemispheres. Stimulus comparisons may be verbal vs. non-verbal, meaningful vs. nonsense, spatial vs. sensory, visual vs. tactual. All of these are ways of manipulating stimuli so that interrelationships can be investigated among them and the side of presentation or the side of the brain lesion if one exists. Bryden (1973) compared right and left visual field recognition of letters, forms and dot localization, while Fontenot and Benton (1972) compared lines of different direction with nonsense verbal stimuli in each visual field. Semmes (1965) related spatial abilities in tactual perception of shape, size, form and texture with actual sensory losses measured in sensitivity to touch, two-point discrimination and point localization. Krauthamer (1968) tested the matching of stimuli across sensory modalities of touch and vision by having normal subjects recognize tactual equivalents of visual stimuli and visual equivalents of tactual stimuli.

It is possible to examine the separate functions of the hemispheres with normal subjects (those with no known brain damage), with subjects who have undergone a deconnection of the corpus collosum (severing connections between the two hemispheres), or with subjects having verified brain lesions which are limited to a single hemisphere.

Sperry (1968) studied neurosurgical patients in whom an extensive midline section of the cerebral commissures had been carried out in order to control severe epilepsy. These patients were left with virtually no connections between the two halves of the brain. In past years, patients with this type of lesion were thought to have no defects in brain function, but with stimuli and responses limited to those controlled by one side of the brain, Sperry and his colleagues were able to single out several cerebral functions specific to each hemisphere. Their method in studying these patients was unique in that great care was taken to be sure that all cues, whether visual, tactual or auditory were strictly controlled to reach only one hemisphere. Stimuli consisted of words or pictures flashed to the right or left visual field, or objects presented to the right or left hand for identification. Responses were then required in verbal or non-verbal form such as naming, writing, drawing or choosing from an array of objects.

Subjects with unilateral brain lesions provide another source of information which is gained from comparing the performance of subjects with right or left cerebral lesions and subjects with no brain lesions. Techniques may be similar to those used with the normal and commissurotomized subjects, except that it is not necessary to control as strictly the isolation of stimuli to the separate sensory fields, and the identifying criterion then becomes the means by which the lesion is verified. Common means of verification are clinical diagnosis, radioactive brain scan, arteriogram, neurological tests and behavioral indices of deficits known to be associated with left or right lesions, such as tests for aphasia, visual field loss or constructional apraxia. Other ways of qualifying a left or right hemisphere lesion are ablation of a specific area as a result of surgery or examination of the brain at autopsy.

Anatomical Division of Sensory and Motor Systems

Anatomically, sensory and motor systems are divided, making possible the isolation of stimuli and responses in each hemisphere. Visual input to each eye is divided into right and left visual half fields. A visual half field can be described in this way: Stimuli in the form of light waves entering the eye from the right side of the body are reflected on the nasal portion of the retina of the right eye and the temporal portion of the retina of the left eye. Nerve fibers leaving the retina make up the optic nerve, and this visual pathway divides at the optic chiasm so that fibers from the nasal half of each retina cross to the opposite side while those from the temporal half leave the chiasm without crossing. The effect of this is that the visual field for each eye is divided, with sensory input from the right visual field going to the cortex of the left occipital lobe, and input from the left visual field going to the right occipital lobe (Manter and Gatz, 1961).

For the tactile sense, afferent fibers have their origins in various end organs located in the skin, muscles and joints, from which they converge and enter the spinal cord via the dorsal root. From there they synapse and cross to the opposite side, ascending as anterior and lateral spinothalamic tracts and posterior funiculi. Before crossing over, some of the fibers turn and travel one or more segments upward, so that the spinal cord contains both crossed and uncrossed fibers. By the level of the brain stem all have crossed to the opposite side where they continue to ascend to the thalamus. From there messages are relayed to the post-central gyrus of the cerebral cortex. In this manner, the sensory modalities of pain, temperature, light touch, deep touch, sterognosis and proprioception are under the influence of the contralateral hemisphere (Gardner, 1963) and (Manter and Gatz, 1961).

Motor fibers, which originate in the pre-central gyrus of the frontal lobes of the cerebral cortex, descend in the internal capsule and collect into bundles of fibers. At the level of the pyramids, approximately 75% of these fibers cross over to the opposite side of the body and descend in the lateral funiculi of the spinal cord, from which they branch to form the efferent peripheral nerves which innervate the muscle fibers. The uncrossed fibers descend either in the anterior or lateral funiculi of the same side (Gardner, 1963).

Functional Division of the Hemispheres

Tactile, motor and sensory abilities are predominately controlled by the contralateral cerebral hemisphere because of the crossing of the tracts, but there is evidence of ipsilateral control at the hemispheric level. Studies by Semmes (1968) reveal that there are two types of asymmetries involving the hands. One involves the difference between the hemispheres in contralateral function and the other a difference in ipsilateral function. Contralateral function was tested in four aspects of sensory ability: sense of passive movement, touch-pressure thresholds, two-point discrimination and point localization. For the right hand, the deficits were found to be maximal after lesions of the left sensorimotor region, but for the left hand, deficits were not found to be clearly related to lesions of the right sensorimotor region. Motor function as measured in loss of strength shows a parallel result to that of sensory loss in contralateral function.

Ipsilateral function also shows a greater deficit with left hemisphere lesions than with right hemisphere lesions supporting the dominance of the left hemisphere with respect to the bilaterality of its role in control of sensation and movement. These studies by Semmes show a qualitative as well as quantitative difference of ipsilateral control in the two hemispheres. The right hand is impaired equally after lesions either within or outside of the right sensorimotor region, suggesting a diffuse representation. In contrast, the left hand is impaired more frequently by lesions in the sensorimotor region of the left hemisphere than outside this region, a result which implies a focal representation.

Laterality studies involving handedness indicate that there exists an interrelationship between handedness as indicated by the degree to which the subject consistently uses a preferred hand in a variety of tasks and cerebral dominance. These data suggest that subjects in whom the right hand is the preferred hand show a greater differential of cerebral laterality than those in whom the left is the preferred hand. In a random sample of right-handed subjects, about 90% will exhibit left cerebral dominance whereas in a random sample of left-handed subjects, about 64% will exhibit left cerebral dominance. Therefore, laterality differences may be expected to be more consistent in right-handers than in left-handers. Also, there is a suggestion that handedness as well as acuity dominance (eyedness) may participate in some degree in a contributing relationship to laterality of speech and spatial functions (White, 1969).

Semmes' (1968) observations point out that in relationship to manual dominance, the hemispheres differ in the effects of parietal lesions. The effects of left cerebral lesions in right-handed people include bilateral apraxia (inability to plan and perform motor acts), bilateral astereognosis (inability to recognize objects by touch) and bilateral finger agnosia (failure to recognize and differentiate individual fingers). This bilaterality of impairment is less often seen in left-handed subjects. Hécaen and Sauguet (1971) compared right and left-handed subjects having unilateral hemisphere involvement on frequency of disturbances on tests of language, reading, writing, calculation, apraxia, somatognosis (body image), visual recognition and recognition of images and colors. In a comparison between the right and left hemisphere syndromes, left-handed subjects showed less difference in frequency of these symptoms than the same comparison in right-handed subjects, suggesting greater cerebral ambilaterality in left-handers.

Spatial Functions

Semmes (1968) describes the role of the hemispheres in complex spatial functions as being subject to the same type of organization as are the motor and sensory modalities. On tests of spatial orientation she found that impairment was related to locus of the lesion (posterior parietal) for the left hemisphere lesions, but not for the right hemisphere lesions, giving evidence for concentration of function on the left, diffuseness on the right. In contrast, a comparison of spatial versus sensory defects revealed an association between impaired orientation and impaired sensation with right hemisphere lesions but not with left hemisphere lesions. The implication of these two dissimilar findings is that in the focally organized left hemisphere, even a small lesion crucially located will produce a deficit in spatial skills, whereas in the more diffusely organized right hemisphere, a small lesion may have no effect but a lesion large enough to disturb spatial functions will tend to disturb sensory functions also. Thus, a small lesion in the focally organized hemisphere can have a dramatic effect on one unitary function without disturbing other functions, but in the diffusely organized right hemisphere, a lesion large enough to show an effect on any one function will affect all the other functions as well. Semmes suggests that it is this diffuse organization which aids in establishing a right hemisphere dominance for spatial abilities due to the high degree of convergence of unlike elements composed of visual, kinesthetic, vestibular and others to combine in an awareness of space.

Other studies also have shown spatial abilities to be more closely related to the right hemisphere than to the left. Nebes (1973) working with commissurotomized patients, found the right hemisphere more competent in perceiving stimulus configuration and orientation of lines than the left. Gainotti and Tiacci (1970) gave tests consisting of design copying to patients with left and right cerebral damage and found that the right hemisphere damaged patients had a tendency to neglect the left half of the drawing, to orient the designs incorrectly and to make errors in spatial relations. In addition they showed a piecemeal approach. In contrast, left hemisphere damaged patients gave simplified and reduced copies and found it difficult to reproduce angles. Hécaen and Assal (1970) tested subjects on the effects of having partial cues in tasks of copying designs and found that spatial deficits due to constructional apraxia in right hemisphere lesions were not influenced by cues, in fact were often aggravated by them.

Butters and Barton (1970) tested patients with right and left cerebral lesions in three tasks requiring the performance of reversible operations in space: matching and reversal of stick patterns, village scene perspectives, and pool reflections (vertical rotations). Results indicated that patients with either right or left parietal lobe damage were impaired on all three tasks, with the right parietal group somewhat more impaired than the left. This suggests that reversible operations like other spatial tasks may be more dependent upon the right hemisphere.

Speech, Language and Verbal Mediation

The functional specialization of the left hemisphere for language and speech in right handers was one of the first hemispheric specializations discovered. Broca, Bastian, Jackson and Wernicke established this phenomenon in the 19th Century working with aphasics. Later investigations have verified the early discoveries with other techniques. Sperry (1968), in his studies of right-handed patients in whom the corpus collosum had been severed deconnecting the two hemispheres of the brain, was able to show that speech and writing were under the control of the left hemisphere, although the right hemisphere was capable of comprehending written and spoken words when a non-verbal response was elicited from the non-dominant hand. In this way, with stimulus and response limited to parts of the body controlled by the right hemisphere, these patients were able to show that they recognized objects by touch, solved simple arithmetic problems, used simple forms of verbal abstraction or mediation, identified odors and demonstrated emotional responses, although they could not verbalize responses to any of these. It was as if there were two independent types of consciousness, each in its own hemisphere, cut off from the experiences of the other, having its own sensations and perceptions and requiring its own type of response. For example, visual material consisting of a word or picture, when presented tachistoscopically to the right visual field (left hemisphere) of a right-handed patient was described in speech or writing in a normal manner. When the same material was presented to the left visual field (right hemisphere) the patient reported he saw nothing but a flash of light, but if asked to use the left hand to point to a matching picture or object presented among a group of pictures or objects, he had little or no difficulty pointing out the object he had just reported he did not see.

Studies with commissurotomized patients conducted by Gazzaniga and Hillyard (1971) further analyzed the language function of the right hemisphere. They found that this hemisphere was unable to relate subject to object via a verb. It was also unable to respond to verb commands or to comprehend the semantic aspect of verbs. They found that the verbal skill of the right hemisphere was mainly in matching noun labels to pictures or objects and in distinguishing negative from positive. Newcomb and Marshall (1967) compared subjects with unilateral cerebral damage with normal subjects on recall of sentences and found that those with left hemisphere lesions were impaired, especially in sentences with reduced semantic constraints, while those with right hemisphere lesions performed as efficiently as the controls, indicating that the left hemisphere was crucial in the more complex verbal skills.

Some studies have been concentrated on the hemispheric organization for speech among left-handers. Hécaen and Piercy (1956) studied 126 patients having lateralized lesions, 97 of whom were right-handed and 29 of whom were left-handed. These patients all had paroxysmal dysphasia occurring as an aura to an epileptic seizure; an acute and short-lived disturbance of normal language function. Analysis of the data revealed that expressive dysphasia occurred more frequently in left-handed patients than in right-handed patients irrespective of the side of the epileptic focus. In right-handed patients, the incidence was greater with left sided lesions, but no such difference was noted in left-handed patients. Receptive dysphasia was rare except in right-handed patients with left cerebral foci. This study leads to the conclusion that in left-handers, language is bilaterally represented in the hemispheres, and that there is more diffuseness of language representation within a single hemisphere in left-handers than in right-handers.

Effects of verbal mediation on the learning of perceptual material and effects of unilateral lesions on the ability to use verbal mediation have been shown. Colgate and Eriksen (1970) presented nonsense forms tachistoscopically in groups of six forms to normal subjects. Half the subjects had learned one-syllable names for the forms, the other half had learned three-syllable names for the same forms. Then the subjects were asked to indicate the six forms they had viewed. The group who had learned the one-syllable names was superior, implying that if implicit naming of the forms was done during and immediately following the tachistoscopic presentation, the longer the implicit name, the more the iconic image decayed. A study with aphasic patients in comparison with those without aphasia showed that the non-aphasics gave evidence of verbal mediation, while the aphasics gave no evidence of covert verbal mediation in coding pictures of familiar objects (Goodglass, Denes and Calderon, 1974). Another study designed to determine if impairments of aphasics in short-term memory can be explained by the "Verbal loop hypothesis" showed that the verbal loop was not essential to memory tasks and favored instead the existence of a non-verbal memory (Heinz, 1973). The implication of these studies is that when language skills are intact, verbal mediation is used, but when language skills are impaired, a non-verbal type of memory may be used.

Visual Recognition

Studies of visual recognition have shown differences in the type of material best identified by each visual field. McKeever and Huling (1971) conducted a study in which normal subjects were asked to identify four-letter words presented briefly and simultaneously to the right and left of a center fixation point. Their results revealed that more words were correctly recognized in the right visual field (projected to the left hemisphere) than to the left visual field. Mackavey, Curcio and Rosen (1975) found that right visual field superiority was maintained whether the stimuli were presented horizontally or vertically, with or without central fixation controls and through variations of exposure durations; although Hines (1972) and Hines and Satz (1971) in two earlier studies had found that by eliminating a center fixation and using slower presentation rates, the right visual field superiority could be reversed or decreased. In studies using tachistoscopic presentation of both verbal and non-verbal material, Kimura (1966) found that letters were more accurately identified in the right visual field (left hemisphere), while enumeration of non-alphabetical stimuli was more accurate in the left visual field (right hemisphere). When presenting normal subjects with stimuli consisting of lines oriented in different directions, requiring the subject to indicate the direction, and of nonsense verbal stimuli consisting of letters, Fontenot and Benton (1972) found that these subjects demonstrated right hemisphere superiority for the lines and left hemisphere superiority for recall of the letters.

Similar studies using as subjects patients with unilateral brain damage have further served to verify the above findings. Rubino (1970) found in visually testing two groups of patients, one with brain lesions in the right temporal area and the other with lesions in the left temporal area, that recognition of non-meaningful words was impaired by left temporal lobe damage and recognition of non-meaningful figures was impaired by right temporal lobe damage. Also, Shai, Goodglass and Barton (1972) found that in patients with middle cerebral artery damage in the right or left hemisphere, there was better recognition of both verbal material (three-letter words of high frequency of occurrence) and non-verbal material (nonsense figures) presented tachistoscopically to the visual field contralateral to the intact hemisphere. The effect of the lesion was greater for verbal stimuli with left hemisphere damage and for non-verbal stimuli with right hemisphere damage. Dorff, Mirsky and Mishkin (1956) gave tasks of tachistoscopic visual recognition of letters to patients with right and left temporal lobe damage and found the performance of both groups inferior to that of normal controls. Moreover, the right temporal damaged group showed impairment in both visual fields, while the left temporal damaged group showed impairment only for stimuli presented to the right visual field.

Tactual Recognition

Sterognosis, or the recognition of objects by touch, is found to be similar but separate in the two hemispheres, with the left hemisphere receiving tactual sensory input from the right hand and the right hemisphere receiving input from the left hand (Sperry, 1968). In the case of unilateral brain damage, some bilateral or ipsilateral impairment of sensation has been found (Carmon, 1971). Even in the absence of other sensory defects, tactual perception of shape may be impaired, suggesting that stereognosis may be related to a spatial factor (Semmes, 1965). Studies of tactual perception in brain damaged subjects has yielded similar results to those of visual perception in regard to the role of the right cerebral hemisphere in spatial tasks. Milner and Taylor (1972) found that in patients with cerebral commissurotomies, matching of tactile patterns was superior with the left hand rather than the right. Fontenot and Benton (1971) found that in patients with unilateral hemispheric lesions, perception of direction of a tactile stimulus to the palm was more impaired in right cerebral lesions, although this impairment was shown to be bilateral. In testing for hemispheric specialization for linguistic versus non-linguistic tactile stimuli, Witelson (1974) found that the non-linguistic material presented to the left hand yielded more accurate responses than that presented to the right hand. Letters were not more accurately identified by the right hand, a fact which suggested that tactile information may first be processed spatially, then translated into language. This was also suggested by Hermelin and O'Connor (1971) with tests of Braille reading in which blind subjects were found to be more accurate with the left hand than with the right hand.

Integration of Sensory Input

It is generally agreed that complex cerebral functioning requires more than sensory input from each of the senses. There must be some degree of integration among the incoming stimuli in order for meaningful perception and learning to occur. Ayres (1972) performed a factor analysis on various tests of sensory perception and found that visual form and space perception are related to tactile and kinesthetic functions. It was further shown that a second factor linked auditory, language and intelligence test scores. Studies of cross-modal transfer between the sensory modalities has helped to reveal some of the integration which takes place. Sperry (1968) in working with commissurotomized patients found that they could transfer information from the visual to the tactual as long as both stimulus and response were limited to the same side of the body. Dee and Benton (1970) chose subjects who had lesions restricted to one or the other cerebral hemisphere and gave tests of tactual and visual perception followed by a praxis test consisting of copying with the hand ipsilateral to the lesion. Their results showed that failure on the construction test was closely related to the tactual as well as the visual, and this was found in patients with lesions in either hemisphere. DeRenzi, Faglioni and Scotti (1970) found in unilateral brain damaged patients that those with right hemisphere damage and visual field defects were more impaired than any other group in tasks of visual and tactual searching, and that in the tactual modality, hemi-inattention does not depend so much on perceptual and motor factors as on a mutilated representation of space.

Butters and Brody (1968) conducted a study with subjects having left hemisphere parietal lesions. These subjects performed intramodal tasks of visual to visual and tactual to tactual; and cross-modal tasks of tactual to visual, visual to tactual and auditory to visual matching. Results of this study showed that these patients with dominant parietal lobe damage were impaired on all cross-modal tasks. Some were also impaired on tactual to tactual matches. As a follow-up study, Butters, Barton and Brody (1970) assessed the role of the right parietal lobe in cross-modal associations and found that severely impaired right parietal patients had no problems with visual to visual matching, were also unimpaired in visual to tactual, but were impaired in tactual to tactual and in auditory to visual matching. From these two studies, the authors concluded that the left cerebral hemisphere was more crucial than the right for cross-modal matching. Normal adults were tested on their ability to recognize the tactual equivalents of visual patterns and the visual equivalents of tactual patterns on a modified paired-associate task (Krauthamer, 1968). Visual and tactual patterns were presented in two ways, either as stationary or as traced contours. Results showed that subjects under all conditions were able to recognize patterns across sensory modalities, but that cross-modal perception was never better than intramodal perception.

Using a transfer of training paradigm, Gaydos (1956) and Walk (1965) measured cross-modal transfer between touch and vision on a paired-associate learning task using normal subjects. Walk used associations between nonsense forms and nonsense syllables, and Gaydos used nonsense forms paired with common boy's names. In both studies subjects learned the associations in one sense modality, either touch or vision, then were tested in the other sense modality. The saving in trials from the first learning task to the second testing task represented the amount of cross-modal transfer. Neither study showed a significant difference between vision and touch in original learning. Gaydos's study showed that there was significant cross-modal transfer and that this was greater from the tactual to visual than from the visual to tactual. Using non-symmetric forms, Walk found also that there was cross-modal transfer, but did not find significant differences between tactual to visual or visual to tactual transfer. He found that differences occurred only by varying the type of forms; the visual group then learned symmetrical forms more quickly than the tactual group.

Goodnow (1971) used matching tasks with normal subjects and found that visual to visual matching was the easiest, visual to tactual and tactual to visual were intermediate in difficulty, and tactual to tactual was most difficult. She suggested that memory gathered by hand was likely to be less stable and to show more loss when the number of comparisons was large. As memory demands increased any matching that began with inspection by hand declined in accuracy before matching that began with visual inspection. Abravanel (1973) found that when presented with a choice between the use of touch or vision to perceive shape, normal adults combined the two when the standard to be compared was tactual, but used only vision when the standard was visual. Results of a study by Zung, Butter and Cashdan (1974) also showed that visual recognition was preferred by most subjects and that when presented with bimodal stimuli, the subjects appeared to seek lesser amounts of information tactually in the presence of visual exposure.

Summary of the Roles of Each Hemisphere

To summarize the specialized roles of the separate hemispheres, it is generally accepted that the left hemisphere assumes the major responsibility for speech and language (including verbal mediation), writing, bilateral control of sensation and movement (including the planning and execution of motor acts), recognition of objects by touch (sterognosis), visual recognition of letters and digits, visual and auditory memory for words and cross-modal matching. Functions of the left hemisphere are believed to be focally represented, with similar abilities located in close proximity to one another. For this reason, a small lesion in one area will produce a definite functional deficit. The right hemisphere in contrast is predominately responsible for spatial perception (including directional orientation of lines, depth perception and form perception), reproduction of block designs, spatial reversals, tactual perception of shapes and letters, discrimination of colors and dressing praxis. The right hemisphere also exhibits language functions but these are limited primarily to concrete noun labels. Unlike those of the left hemisphere, functions of the right hemisphere are believed to be diffusely represented, with dissimilar elements closely approximated to give a combined sensory awareness of space.

Taking into account the several facets of cerebral function, the present study was designed to measure cross-modal transfer between touch and vision in patients with unilateral brain damage on a form-letter paired-associate task. It was expected that performance of the brain-damaged groups would be inferior to the performance of normal subjects. Also, it was expected that original learning would be easier with stimuli presented visually rather than tactually, and that cross-modal transfer from tactual to visual would be greater than from visual to tactual. This study was similar to those performed by Gaydos in 1956 and Walk in 1965, but it compared performance of patients with unilateral lesions with that of subjects without brain lesions (hereafter referred to as normal subjects).

Hypotheses

H_1 Studies conducted with both left and right brain-damaged subjects have shown that performance on various visual and tactual tasks as well as on some cross-modal tasks between visual and tactual learning is less efficient in the presence of brain lesions. It is therefore expected that if the subject has unilateral brain damage in either the right or left hemisphere, then he will demonstrate less cross-modal transfer than a subject with no brain damage.

H_2 Studies have indicated that cross-modal transfer between touch and vision is more a function of the left hemisphere than of the right hemisphere. Therefore, it is expected that the left hemisphere damaged group will demonstrate inferior performance to the right hemisphere group in cross-modal transfer.

H_3 The evidence suggests that the left hemisphere is dominant for verbal performance. Thus it is predicted that if a subject has left hemisphere damage, he will demonstrate inferior performance in the initial learning tasks than if he has right hemisphere damage.

H_4 Studies indicate that in normal subjects, tactual recognition of all stimuli, even letters, is more efficient with the left hand, leading to the assumption that tactual recognition is a spatial factor. It has also been found that in perception of a tactual stimulus to the palm, patients with right cerebral lesions are more impaired than those with left lesions. It is predicted that if the subject has right hemisphere damage, then he will have more difficulty with tasks in which the stimuli are tactual than with tasks in which the stimuli are visual.

H_5 When presented with bimodal stimuli and given a choice between visual and tactual modalities, normal subjects use the visual modality more than the tactual and find visual matching easier than tactual matching. It is therefore predicted that tasks in which the stimuli are visual will require fewer trials to learn to criterion than tasks in which stimuli are tactual.

H_6 Since visual learning is easier than tactual learning, it is expected that tactual tests will require more initial trials than visual tests, but due to overlearning, cross-modal transfer from tactual to visual modalities should be greater than from visual to tactual.

CHAPTER II

SUBJECTS

Three groups of subjects participated in the experiment. Two of the groups were chosen from available in-patients and out-patients at Emory University Hospital and from in-patients in the Rehabilitation Unit at Grady Memorial Hospital. Two groups had verified brain lesions, one groups' involving the left hemisphere and the second groups' involving the right hemisphere. A third group was chosen from the same patient populations and from spouses of patients in the first two groups. This third group was a control group with subjects having no known brain lesions. Each subject signed a release giving permission for his or her test result to be used.

In the two brain-damaged groups, unilaterality of the lesions was verified either by a CAT (Computerized Axial Tomography) brain scan, by arteriogram, or by the clinical diagnosis taken from the patient's hospital record. In addition, the severity of the physical manifestations of hemiparesis and aphasia was judged by the examiner* by observation according to the following criteria: severe--complete or nearly complete loss of function; moderate--partial loss of function with much difficulty; mild--slight or no loss of function but residual impairment noted.

*Experimenter is a registered Occupational Therapist with experience in working with neurologically impaired patients.

All subjects were interviewed briefly before testing regarding their availability for testing and their medical history. This served to eliminate those who, due to disorientation, would not be able to understand what was expected in the test as well as those whose medical problems might affect the ability to be tested.

Distribution of the subjects according to sex, side of lesion and age is shown in Table 1. All except two of the subjects were right-handed by self-declaration. Pathology of the brain lesions was listed as cerebral vascular accident for 17 patients, tumor for one patient and gunshot wound for one patient. In the control group, two subjects were spouses of patients, one was paraplegic, one had a traumatic left arm lesion and four had arthritis. Of the arthritic subjects, none experienced sufficient sensory or motor loss which would affect their ability to perform the tactual recognition task.

Table 1. Distribution of Subjects

Total Number	Male	Female	Side of Lesion	Age Range	Number Completing Test
9	4	5	L	21-68	2
10	6	4	R	23-73	8
8	4	4	0	21-78	8

CHAPTER III

PROCEDURE

Each subject was seen for one individual test session which lasted approximately one hour. Paired-associate tasks were presented in which the subject learned an association consisting of a nonsense form paired with a letter of the alphabet. The associations were learned in one modality, either touch or vision, then were immediately tested by relearning to criterion in the other modality. For each learning/relearning task, the same forms and letters were used, only the modality of presentation was changed. Both the original learning and relearning were measured by the number of trials required to reach a criterion of two correct trials. Half the subjects in each group learned the task tactually first and then were tested for transfer to vision, and the other half learned the task visually first and were tested for transfer to touch. Assignment to these two conditions was random within each subject group with the restriction that half the subjects performed under each original learning condition.

Ten stimulus objects consisted of nonsense shapes similar to Gaydos's forms (1956). They were constructed of masonite and were about two inches in diameter with a notch cut into one side for spatial reference. Each form was paired with a letter of the alphabet. Five of these forms were picked at random for each learning and transfer task so that any difference in the difficulty of the pairs was randomized.

For the tactual learning task, the subject's hands were placed behind a shield. Five forms were presented one at a time and the letter to be associated with it indicated verbally and by placing the printed letter on a rack in front of the subject. The forms were placed with the notched side facing the subject. The subject was instructed to manipulate each form in his hands. There was no restriction on the choice of hand, and in the case of the two groups with brain lesions, the hand ipsilateral to the side of the lesion was most often used. In subsequent trials, after the five forms and their respective letters had been presented one time, the subject was instructed to attempt to indicate the correct letter in the group of letters containing all five letters used in the task. The method of indicating the letter was by a verbal response or by pointing. Pointing was encouraged even when a verbal response was made. The forms were randomly presented in a different order for each trial. No time limit was placed on the subject's responses; however, it was noted that subjects gave responses in approximately one minute or less. After the subject had indicated his answer or his inability to identify each form, the correct response was given so that the subject could have an immediate check on his response and an opportunity for learning. Trials continued until the criterion of two subsequent correct trials had been reached.

The visual learning task proceeded in the same way except that the subject was not permitted to touch the form. The forms, one at a time, were placed in front of the subject as before with the notched side facing the subject. The letter names for each form were indicated. As in the tactual trials, on subsequent attempts, the subject was instructed to indicate the letter to be associated with each form. Trials continued to a criterion of two consecutive correct trials.

In some cases, subjects were unable to reach criterion on the original learning task. When this occurred, the experimenter's decision to end the test was based on any one of three conditions: responses continued to be so inconsistent it was obvious the subject was guessing; the subject expressed desire to stop due to frustration, failure to understand the task or fatigue; or after more than one hour of testing, criterion had not yet been reached.

Tactual and visual transfer tasks were identical to the learning tasks with one exception; letter names were not indicated to the subject on the first trial, but the subject was instructed to begin by attempting to indicate the correct letter. Trials in the transfer task continued to a criterion of two consecutive correct trials.

CHAPTER IV

RESULTS

Scores from the right brain-damaged group and the non brain-damaged group are included in the analysis; but scores from the left brain-damaged group were not included as only two subjects from this group were able to complete the tests.

Test results for each subject were measured in two ways: (1) the number of trials required to reach the criterion of two consecutive correct trials and (2) the number of errors made in each task before the criterion was reached. Table 2 shows the raw data for each group and type of task according to the number of trials to criterion and number of errors in the original learning and transfer tasks.

Two separate analyses were made. For each, the raw scores were converted into ranks and analyzed by using the Kruskal-Wallis Analysis of Variance by Ranks (Kirk, 1968). The first analysis was done using the number of trials to criterion. In the learning or initial task, the dependent variable was the actual number of trials to learn, converted into a series of ranks. In the transfer task, the dependent variable was the savings scores (trials to criterion in the original learning minus trials to criterion in relearning divided by trials to criterion in original learning). These scores also were converted into ranks. As a further check on the savings score method, an analysis was also made on the ranks of the actual number of trials in the relearning task. Results of this analysis were consistent with the others and thus were not reported.

A second analysis was made on the number of errors to criterion in the learning task and on the savings scores based on errors. As in the first analysis, the figures were converted to rank order before analysis by the Kruskal-Wallis method. Table 3 shows the results of the analyses by trials to criterion and by errors.

There was a significant difference in both trials to criterion and in errors for the initial learning test between the subjects with right brain lesions and those with no brain lesions, with the normal subjects demonstrating superior performance. It was predicted that in the initial learning, subjects with left brain lesions would demonstrate inferior performance to the subjects with right brain lesions. This prediction was not tested statistically, but was nevertheless supported by the fact that only two of the nine subjects in this group were able to reach criterion in the initial learning test.

In cross-modal transfer, the prediction that the two brain-damaged groups would demonstrate less cross-modal transfer was not supported in the case of the right brain-damaged group, and could not be tested for significance in the case of the left brain-damaged group due to the small number completing the test.

Predictions regarding differences between visual and tactual learning were not supported. Results showed that there was no difference in the performance of the right brain-damaged subjects whether the stimuli were presented visually or tactually in the initial learning task. Similarly, there was an insignificant difference in the performance of all subjects in original learning between visual and tactual stimuli.

Since no significant differences between visual and tactual learning occurred in original learning, savings scores could be used to measure cross-modal transfer, and as shown by these savings scores, cross-modal transfer from visual to tactual modalities did not differ significantly from transfer from tactual to visual modalities.

Table 2. Raw Scores for Number of Trials to Criterion and Number of Errors in Original and Relearning Tests

		Visual		Tactual	
		Trials	Errors	Trials	Errors
ORIGINAL LEARNING					
Right	M	11,12	09,15	18,13	32,15
Hemisphere				12,13	16,17
Lesions	F	18,26	19,55		
No	M	12,09	11,13	10,03	13,01
Lesions	F	10,05	12,06	02,02	0,0
RELEARNING					
Right	M	05,03	03,02	04,02	03,0
Hemisphere		05,05	02,09		
Lesions	F			09,24	06,43
No	M	05,05	05,02	07,02	08,0
Lesions	F	04,02	01,0	02,04	0,01

Table 3. Results of Analyses by Number of Trials and by Errors Using Kruskal-Wallis One-Way Analysis of Variance*

	Number of Trials	Errors
ORIGINAL LEARNING		
Right Lesions vs. Controls	9.88**	8.53 **
Visual Learning vs. Tactual Learning	.26	- .037
Right Lesions vs. Visual vs. Tactual	- .1	- .09
TRANSFER		
Right Lesions vs. Controls	2.182	.967
Visual-Tactual vs. Tactual-Visual	1.072	1.724

*χ^2 .05,1 = 3.841

**$p < .01$

CHAPTER V

DISCUSSION

Results from this study upheld predictions of difficulty in original learning in the presence of brain damage. However, in cross-modal transfer between touch and vision and in differences between visual and tactual learning or transfer, the data did not support hypotheses consistent with earlier studies or with predicted results.

Original learning was expected to present the most difficulty for those subjects with left hemisphere lesions. This proved to be true to the extent that of the nine subjects tested, only two were able to reach the criterion of the original learning task. Although seven of these subjects demonstrated some form of aphasia ranging from mild to severe, this does not account solely for their failure in this task, because the responses did not require an overt verbal response. Also, the two subjects who were able to complete the task both were aphasic, one rated as mildly aphasic, the other severely impaired in expressive language. Verbal mediation, identification of meaning and learning aspects of this paired-associate task which required learning to criterion appear to be determining factors working most detrimentally against patients with left hemisphere lesions. Several studies support these factors. Butters and Brody (1968) in assessing the role of the dominant angular gyrus, found evidence that intersensory associations, especially visual-auditory or tactual-auditory were important for reading and object naming. The written word or the visually or tactually presented object must be mediated by an appropriate auditory associate to be named.

Several studies have supported the role of the left hemisphere in identification of meaning. DeRenzi (1968) found in a paired-associate task which involved memorizing meaningful and nonsense figures, that aphasia was an important factor in inability to memorize both types of stimuli. He suggested that subjects do attempt to learn nonsense figures by attributing to them a meaning. This would explain in part the failure to learn the nonsense figures as well as the meaningful ones. It further suggested that a loss of intellectual ability mediated by the same or adjacent areas to language functions resulted in impairment, not only because names were no longer available, but because of failure to be able to transform meaningless figures into meaningful ones. Remarks made by subjects in the left hemisphere group in the present study, who were experiencing failure on the learning task, tend to lend some support to DeRenzi's conclusions. Typical of these remarks were, "It doesn't make any sense," and "I just can't see any connection between this shape and the letter."

Two other studies dealing with identification of meaning found left hemisphere damaged subjects to demonstrate inferior performance to the right hemisphere damaged and control groups. Boller and DeRenzi (1967) required subjects to memorize meaningful and nonsense figures. Results suggested that subjects may have tried to memorize meaningless form by attaching a meaning to them. DeRenzi, Scotti and Spinnler (1969) required subjects to recognize four types of visual stimuli, three of which were apperceptive in nature, requiring subtle visual discrimination; the fourth was associative, requiring the subject to match similar objects. Results of this study showed that the left hemisphere damaged group performed poorly on the associative test, again implicating the importance of that hemisphere in the higher gnostic function of mediating meaning.

The type of task appears to have some bearing on the inferior performance of the left hemisphere damaged group. Butters and Barton (1970) suggested that the learning-to-criterion condition was doubly difficult for the left hemisphere damaged subject, requiring him not only to make a judgment, but to learn it as well, which would be difficult due to his impairment in language. The right hemisphere damaged subject may have experienced initial difficulty due to spatial impairments, but did not experience learning difficulties due to aphasia, thereby appearing less impaired than the left hemisphere group. DeRenzi (1968) also commented that left hemisphere damaged patients demonstrated inferior performance with paired-associate techniques while right hemisphere damaged patients demonstrated inferior performance with recognition of recurring figures. He attributed this to the possibility that in the paired-associate task, the right hemisphere damaged subjects could add a verbal trace to the visual trace, whereas in the recurring figures task they had to rely on the visual trace alone.

The right hemisphere damaged group, although superior to the left hemisphere damaged group in that the subjects were able to complete the original learning test, was nevertheless significantly inferior to the control group. Earlier studies cited support the fact that part of the deficit could have been accounted for by difficulty in the spatial aspects involved in identification of the nonsense forms in this study. Other factors are implicated also. Butters and Barton (1970) suggested that spatial factors associated with right hemisphere lesions were minimized by having the subject proceed to a criterion of correct performance. If this were the case in the present study, then the possibility of verbal functions being present in the right hemisphere is suggested, since Sperry (1968) and Gazzaniga and Hillyard (1971) found in their work with commissurotomized patients that the right hemisphere was capable of attaching noun labels to objects.

In regards to cross-modal transfer, although predictions that brain lesions would lead to inferior performance were not supported, results in this study were nevertheless consistent with two earlier studies regarding the right hemisphere. Butters, Barton and Brody (1970) found that right parietal lobe lesions did not result in deficits in a tactual-visual or visual-tactual cross-modal matching test. They did not compare this right hemisphere group with normal subjects however. Sperry (1968) also found the right hemisphere capable of cross-modal transfer in visual-tactual matching. These findings were also seen in the present study on a paired-associate test, and, although the right hemisphere group demonstrated definite inferiority in original learning, its performance on transfer as measured by saving scores was not significantly different from that of the control group.

Differences between visual and tactual learning failed to materialize in this paired-associate test. There was not a significant difference between the modalities of presentation in original learning either for total subjects or for the right hemisphere group. In similar studies using paired-associate learning, Gaydos (1956) failed to find significant differences in original learning using non-symmetrical forms while Walk (1965) found visual learning easier with symmetrical but not with non-symmetrical forms. This present study was compatible with both Gaydos's and Walk's results. Studies using methods other than paired-associate tasks have tended to show that visual learning is easier than tactual learning and that right hemisphere lesions produce greater deficits in the tactual than in the visual modality. Goodnow (1971) suggested in her study with normal children on matching tactual and visual stimuli that memory for information acquired tactually was likely to be less stable and to show more loss when memory demands grew larger than information acquired visually. DeRenzi, Faglioni and Scotti (1970) found that right hemisphere damaged patients were significantly inferior to left hemisphere damaged or control groups in tactual searching.

There was similarly no difference in cross-modal transfer between the two modalities. Results of other experimenters in comparing visual-tactual with tactual-visual transfer have been varied. Gaydos (1956) found visual-tactual easier. Walk (1965) in a similar study did not support this finding. Cashdan (1968), using adaptations of Gaydos's nonsense forms, found visual-tactual better, but on replication, found the opposite. These three studies used normal subjects, the present study a combination of normal and right hemisphere damaged subjects, but it appears that no clear conclusions can be drawn regarding the relative difficulty between visual-tactual versus tactual-visual transfer.

Results of this study have in some cases upheld results of earlier studies, in other cases have failed to show any significant differences. It is suggested that the small number of subjects, plus the large variability of the subjects within groups may have affected results to some degree. Also, the nature of the task, which was a paired-associate task requiring learning to criterion, verbal mediation and memory may have led to results which differed from those established by tasks requiring matching, short-term or non-verbal memory.

Implications of this study are that clear deficits in initial learning exist in the presence of either right or left hemisphere lesions, being especially severe for those patients with left hemisphere damage, when the task involves identification of meaning. Equally important is the fact that, at least for right hemisphere damaged patients, transfer between the visual and tactual modalities is not affected so that stimuli could be presented to the least damaged of the two or to a combination of both. In the re-training of adults who have had cerebral vascular accidents or other unilateral lesions, treatment must vary according to the nature of the lesion. It is especially useful to realize the difficulty in learning new concepts, especially with left hemisphere lesions. It is equally useful to realize the value of multi-modal learning. Additional studies are needed to find better ways of presenting original learning and transfer for the left brain-damaged patients.

APPENDIX

Data for Right Hemisphere Damaged Group

Sex	Age	Handed-ness	Locus and Type Lesion	Hemiparesis	Aphasia	Modality	Trials	Errors
F	54	R	CVA, Lacunar Infarct	Mild	None	V/T	18/09	19/06
F	36	R	CVA, R Carotid Artery Aneurysm	Moderate	None	V/T	26/24	55/43
M	59	R	*CVA, R Parietal Hematoma	Mild	None	T/V	18/13	32/03
M	67	R	CVA, R Internal Capsule	Severe	None	T/V	13/03	15/02
M	73	R	*CVA, R Parietal	Mild	None	V/T	11/04	09/03
M	42	R	CVA, R Middle Cerebral Artery Embolus	Severe	None	T/V	12/05	16/02
M	37	R	**CVA, R Middle and Anterior Cerebral Arteries	Moderate	None	V/T	12/02	15/0
M	23	R	*CVA, Hematoma Anterior Basal Ganglia	Moderate	None	T/V	13/05	17/09
F	70	R	CVA, Anterior Cerebral Artery Infarct	Severe	None	V/T	---	---
F	73	R	CVA, Thrombotic Stroke	Severe	None	T/V	---	---

*Brain Scan; **Arteriogram; All others by clinical diagnosis.

Data for Left Hemisphere Damaged Group

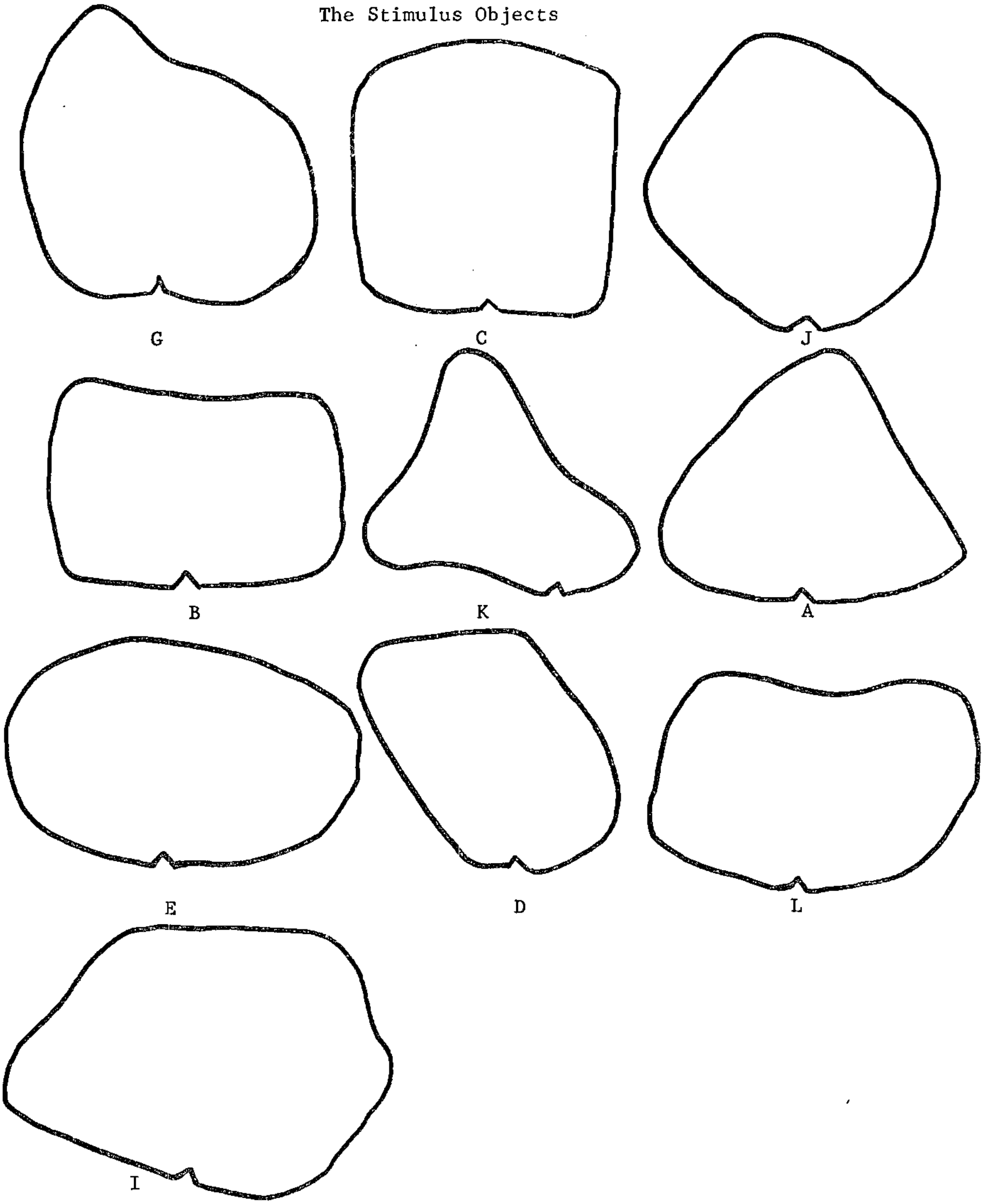
Sex	Age	Handed-ness	Locus and Type Lesion	Hemiparesis	Aphasia	Modality	Trials	Errors
M	61	R	*Tumor, L Parietal	Mild	Mild	V/T	16/02	28/0
M	36	R	CVA, L Middle Cerebral Artery	Moderate	Severe	T/V	14/04	25/03
M	68	R	CVA	---	Severe	V/T	---	---
M	57	R	**CVA, L Anterior Cerebral Artery Aneurysm	None	Mild	T/V	---	---
F	61	R	CVA, Lacunar Infarct	Severe	Mild	V/T	---	---
F	54	R	**Arterio-venus Malformation, Occipital-Parietal	Mild	Mild	V/T	---	---
F	47	R	CVA, Internal Capsule	Moderate	Mild	T/V	---	---
F	28	L	Cerebral Empolism	Severe	Moderate	T/V	---	---
F	21	R	Gun-shot Wound	Severe	---	V/T	---	---

*Brain Scan; **Arteriogram; All others by clinical diagnosis.

Data for Control Group

Sex	Age	Handed-ness	Locus and Type Lesion	Hemiparesis	Aphasia	Modality	Trials	Errors
F	61	R	Arthritis	None	None	V/T	10/02	12/0
F	38	R	Arthritis	None	None	V/T	05/04	06/01
F	35	R	Spouse of Patient	None	None	T/V	02/04	0/01
F	21	R	Spouse of Patient	None	None	T/V	02/02	0/0
M	36	R	Paraplegia	None	None	V/T	12/07	11/08
M	57	R	L Arm Injury	None	None	T/V	10/05	13/05
M	60	R	Arthritis	None	None	T/V	03/05	01/02
M	78	R	Arthritis	None	None	V/T	09/02	13/0

The Stimulus Objects



Sample Calculation

Ranked Scores for Trials to Criterion in Original Learning

		Visual	Tactual	Totals
Right Hemisphere Lesions	Male	7.0, 9.0	4.5, 2.5, 7.0, 4.5	38.0
	Female	2.5, 1.0		
No Lesions	Male	12.0, 7.0	10.5, 14.0	98.0
	Female	13.0, 10.5	15.5, 15.5	
Totals		62.0	74.0	136.0

$$H = \frac{12}{N(N+1)} \left[\sum_{j=1}^{k} \frac{\left(\sum_{i=1}^{n} R_{ij} \right)^2}{n_j} \right] - 3(N+1)$$

$$= \frac{12}{16(16+1)} \frac{(38)^2}{8} + \frac{(98)^2}{8} - 3(16+1)$$

$$= .044\ [180.5 + 1200.5] - 51$$

$$= .044\ [1381] - 51 = 9.76$$

$$H' = \frac{H}{C}$$

$$C = 1 - \left[\frac{\Sigma(t^3-t)}{N^3-N} \right]$$

$$= 1 - \left[\frac{4((2)^3-2) + ((3)^3-3)}{(16)^3 - 16} \right] = .988$$

$$H' = \frac{9.76}{.988} = 9.88$$

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